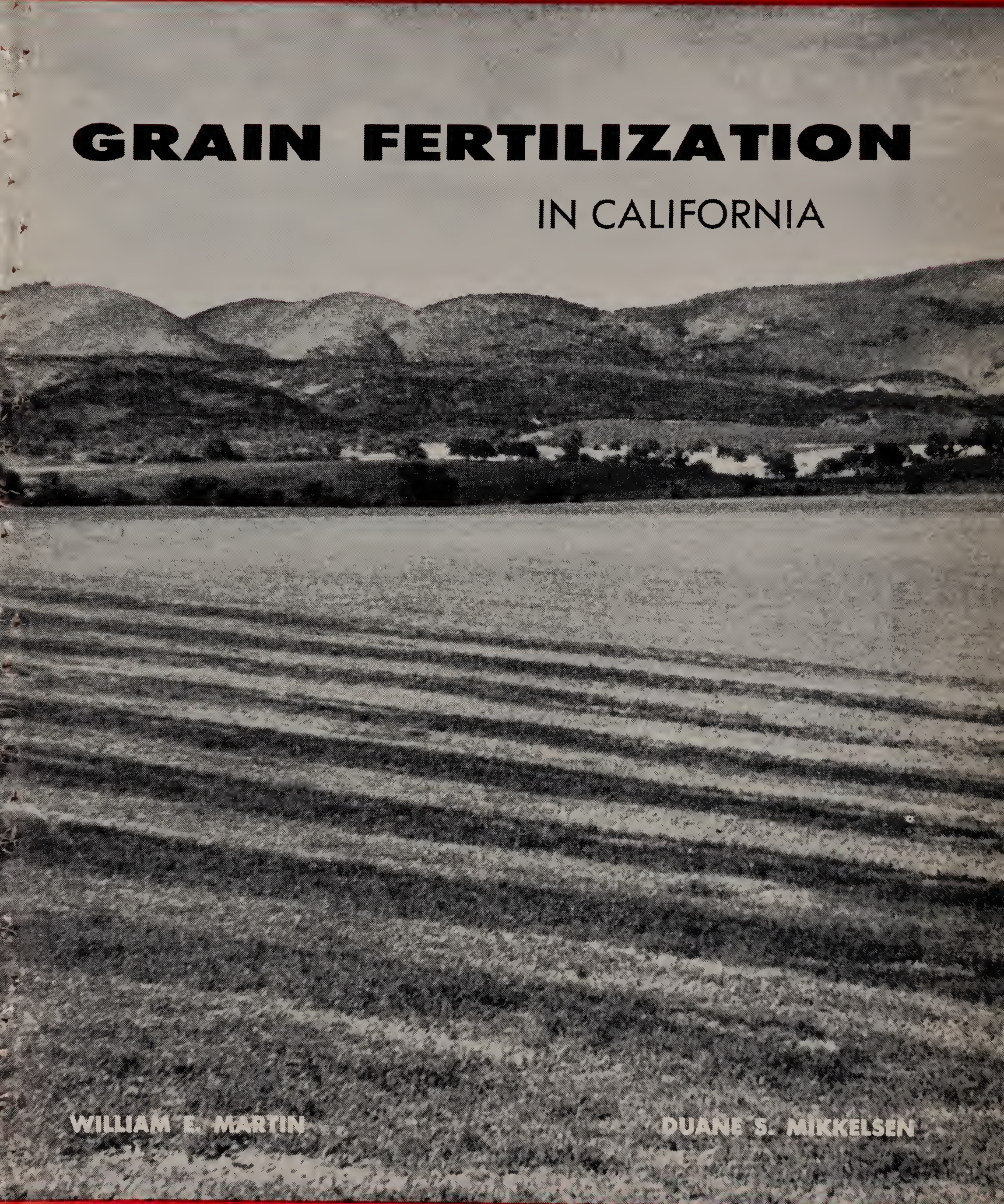
Division of Agricultural Sciences
UNIVERSITY OF CALIFORNIA

GRAIN FERTILIZATION

IN CALIFORNIA



WILLIAM E. MARTIN
DUANE S. MIKKELSEN

CALIFORNIA AGRICULTURAL
Experiment Station
Extension Service

BULLETIN 775

THIS BULLETIN

summarizes the results of a five-year field study on grain fertilization. A total of 221 coordinated field tests was carried out in 38 counties by the Agricultural Extension Service in coöperation with the Department of Agronomy. The study was made during the period 1947 through 1951, on farms selected by the University of California Farm Advisors as typical of the grain-producing areas of their counties.

Results of this program have been released locally in the counties involved and have formed the basis for fertilizer recommendations for those areas and a starting point for additional local fertilizer tests. The purpose of this report is:

1. To present results of the entire program of field fertilizer tests.
2. To show the fertility status of grainlands in various regions throughout the state.
3. To indicate what fertilizers may most effectively be used on grainlands under the varying systems of culture and climatic conditions of the state.

THE AUTHORS:

William E. Martin is Agriculturist in Agricultural Extension, Davis.

Duane S. Mikkelsen is Associate Professor of Agronomy and Agronomist in the Experiment Station, Davis.

The cover picture, taken in 1950, shows the area cropped for 75 years. The alternate strips illustrate the farmer's method of determining the actual benefits of fertilizer recommendations developed from University test plots in the area. In this case a fertilizer attachment was placed on one of the two grain drills pulled in tandem in seeding the field. Approximately 90 pounds per acre of "16–20" ammonium phosphate sulfate were applied.

NOVEMBER, 1960

PURPOSE AND METHODS

Barley, wheat, and oats are grown on a larger total acreage than any other single cultivated crop in California. Figures from the California State Crop and Livestock Reporting Service, for the years 1956, 1957, and 1958, show an average of 1,885,000 acres of barley, 350,000 acres of wheat, 205,000 acres of oats, and 528,000 acres of grain hay harvested in the state. Grain is grown commercially in nearly every county, and is a major crop in all important agricultural counties from Imperial and San Diego on the south to Siskiyou and Modoc on the north.

Grain is grown under a wide variety of climatic conditions. In irrigated areas it is commonly grown in rotation with other crops. In many other areas it is grown without irrigation, under an alternate grain-fallow system where rainfall is not sufficient for annual production. In some areas of California where rainfall is adequate, grain is grown annually without irrigation.

Grain has been a major crop in California for about a hundred years, and was the first important field crop grown on any extensive acreage. In many areas it was formerly grown annually, with the stubble burned following each crop. Many lands now in production have been raising grain annually or biennially for 60 to 80 years.

In some regions where grain has been grown continuously for 50 years or more, soil fertility has been seriously depleted, and in many instances, soil structure has been impaired and soil organic matter greatly reduced. Samples were taken in Monterey County from a field devoted to grain for approximately 75 years. An adjacent piece of land of the same soil series was cleared of brush and oak and added to the original grain field in 1949. Soil samples were taken from the two sections of the field in 1953. The newly cleared land, after two years of cropping, contained 3.6 per cent organic matter, as compared with only 1.35 per cent in the field cropped for 75 years. This would indicate a loss of 63 per cent of the original organic matter during the period of cropping. (See cover photograph, and legend inside cover.)

Production of cereals on some of the older grain areas has dropped to uneconomic levels. Some such soils are commonly referred to as "wornout grainlands." Some have reverted permanently to use as range, while others are cropped only occasionally, with several years of pasture between crops of grain. With the pressure of expanding agriculture in California and an increase in land values, it is important that means be developed to improve the productivity of wornout grainlands and maintain and improve productive capacity of the better land now devoted to grain production. One of the principal purposes of the current study was to determine to what extent commercial fertilizers might restore the productivity of depleted grainlands and a second, to determine what fertilizer should be applied to currently productive land to bring about production as great as is economically possible under the climatic conditions of the areas involved. A further objective of this coördinated study was to develop an inventory of information on the fertility status of a wide range of California soils and to classify those groups and series where fertility problems might be corrected by the use of commercial fertilizers.

Fig. 1. Effect of nitrogen and phosphorus on yield of annual barley. Above: phosphorus with no nitrogen. Below: phosphorus with 15 pounds nitrogen per acre.

How Field Tests Were Conducted

Previous fertilizer work in many of the counties of the state had indicated that nitrogen and phosphorus were the nutrients most likely to increase yields. In the earlier tests, however, no concerted effort was made to correlate soil series with fertilizer response or to lay out tests in such a way that the effects of individual fertilizer nutrients might be studied alone and in combination with each other. Much valuable local information was developed in these tests, but the rate and time of application and the materials employed differed so greatly that results could not be assembled and compared on a statewide basis.

The present study, described in the sections that follow, was made up of 221 tests, including locations in all of the principal grain-producing areas of the state. Of these tests, 149 were with barley, 62 with wheat, and 10 with oats. Forty-five were on irrigated lands, while 176 were on lands dependent on natural rainfall.

The first 25 tests were exploratory in nature, designed to determine what nutrients were deficient. Such tests involved applications of nitrogen, phosphorus, and potash, each nutrient alone and in com-

Fig. 1A. Effect of nitrogen and phosphorus on yield of annual barley. Above: phosphorus with 30 pounds nitrogen per acre. Below: phosphorus with 45 pounds nitrogen per acre.

bination with each of the others. Fertilizer materials were broadcast at planting time and applied in strips to facilitate visual comparison. At some locations the exploratory tests were expanded to include sulfur.

The second group of 196 tests consisted of rate experiments set up to determine how much nitrogen and phosphorus should be applied for most efficient grain production. The treatments in these nitrogen-phosphorus rate tests employed four rates of nitrogen and, at each nitrogen level, four rates of phosphorus. This gave a total of 16 treatments, which were replicated four times in most instances. During the first two seasons, 1947 and 1948, rates of 0, 10, 20, and 40 pounds of nitrogen were used, along with 0, 10, 20, and 40 pounds P_2O_5 per acre at each nitrogen rate. In the last three years, nitrogen rates were changed to 0, 15, 30, and 45 pounds, and phosphorus applications to 0, 20, 40, and 80 pounds P_2O_5 at each nitrogen level. In the first two years, fertilizer materials were broadcast at planting time and land was seeded in the customary fashion by the farmer coöperator. In such tests, individual subplots were 20 feet by 20 feet.

Beginning in 1948, a modified rod row technique was employed, similar to that

Nitrogen applied	Yield per acre* of barley with P_2O_5 applied at: 0 lb/A	20 lb/A	40 lb/A	80 lb/A
lb/A	*lb*	*lb*	*lb*	*lb*
0	758	1,028	1,080	1,163
15	945	1,470	1,665	1,910
30	863	1,583	1,778	1,958
45	1,237	1,560	1,875	2,048

* LSD (0.05) between treatments = 411 lb/acre.

used for testing grain varieties. In these tests each treatment consisted of three rows of grain, 20 to 40 feet long and 1 foot apart, with 16 feet of the middle row harvested for yield. The fertilizer materials used in the rod row tests were mixtures of ammonium sulfate, single superphosphate, and sand, varying in composition so that a rate of 480 pounds per acre gave the requisite amounts of nitrogen and phosphorus in a single application. After the fertilizer had been applied in rows 2 to 3 inches deep and 1 foot apart, grain was seeded with a single-row, hand-seed drill 1 inch to the side and 1 inch above the fertilizer band.

A typical rod row fertilizer test with annual barley on a soil responding to both nitrogen and phosphorus is shown in figures 1 and 1A. Pounds per acre of barley at harvest from this test were as shown in the table above.

All fertilizer plots were put out by University of California Farm Advisors, in fields selected as typical of the grain-producing areas of their counties. The same variety and kind of grain were seeded as were used in the balance of the field. Rod row plots were weeded as necessary during the growing season. At harvest time, 16 square feet from each treatment were clipped by hand, and the clippings were placed in paper bags and sent to the Department of Agronomy at Davis for yield and quality evaluation.

How Results Are Expressed

Yields were calculated on a weight basis, with results expressed as pounds of grain per acre rather than bushels, as commonly used in other sections of the country. *Amounts of nitrogen* applied as fertilizer *always refer,* in this bulletin, *to pounds of actual nitrogen per acre.* In discussing the effects of fertilizer on quality of grain, nitrogen values were converted to per cent protein.

Fertilizer phosphorus applications are usually expressed as pounds of available P_2O_5 per acre. In this bulletin, where reference is made to fertilizer applications and their effects, the terms P, P_2O_5, and phosphorus have been used interchangeably, but amounts always refer to pounds of P_2O_5 per acre. In the section on soil analysis, results of tests for available phosphorus are expressed as phosphate (PO_4).

Laboratory and Greenhouse Studies

Soil samples for laboratory and greenhouse studies were taken at time of planting from as many locations as possible (Jenny *et al.*, 1950).[1] A total of 159 samples was taken from the 221 field tests in this study. After threshing, grain samples were set aside from selected plots for chemical studies and bushel weight measurements to determine the effects of fertilizer treatments upon quality of the grain. Subsequent to the field studies, detailed laboratory examination was made of the soil samples to correlate soil analysis with the fertilizer results obtained.

The object was to find a reliable method for prediction of cereal fertilizer needs.

[1] See "Literature Cited" for citations referred to in the text by author and date.

SUMMARY OF RESULTS — STATEWIDE

What Nutrients Increased Yields?

Results of 221 field tests in 38 counties showed some very striking responses to fertilizers. In 74 per cent of these tests, yields were improved, while 26 per cent showed no benefit from fertilization. The proportion of soils found deficient in each nutrient is shown in figure 2. A summary of the observed responses to fertilization in each of the 38 contributing counties is shown in Appendix table 1A (p. 37).

A quarter of the 221 areas tested either did not need fertilization or failed to respond because of inadequate soil moisture. About a third of the tests responded to nitrogen alone but showed no benefit from phosphorus. A sixth, or 16 per cent, responded to phosphorus alone with no effect of nitrogen, while 26 per cent needed both nitrogen and phosphorus for maximum yield.

Grainlands were classified as phosphorus-deficient (1) where phosphorus alone increased yields or (2) where phosphorus plus nitrogen gave higher yields than nitrogen alone. Combining the two classes of response in which phosphorus was beneficial shows that 42 per cent of the grainlands was deficient in phosphorus.

Similarly, tests were considered to show nitrogen response (1) where nitrogen alone increased yields or (2) where nitrogen plus phosphorus gave significantly higher yields than phosphorus alone. Combining these two groups indicates 59 per cent of the grainlands sampled to be deficient in nitrogen.

No coördinated tests were conducted with potash fertilizers over the entire area. However, in conjunction with the tests above, 34 field tests were laid out in which nitrogen plus phosphorus treatments were compared with the same amounts of nitrogen and phosphorus plus potassium. In no case was there a significant response to the added potassium.

Sulfur is known to be a factor in grain production at some locations, but areas and effects cannot be delineated.

Where Were Phosphorus Deficiencies Found?

Regions of phosphorus deficiency

The responses to fertilization have been plotted on the map of California shown in figure 2. It may be seen that phosphorus-deficient soils occur in many sections of the state. The most striking zone occurs on the terraces and foothills at the east edge of the San Joaquin and Sacramento valleys, extending from Porterville on the south to Oroville on the north. A similar group of plots showing phosphorus deficiency lies on the western edge of the Sacramento Valley. The other two principal zones are in coastal San Diego and Orange counties and in the region between Paso Robles and Shandon in San Luis Obispo County, as well as in the near-by Lockwood Valley of Monterey County. Some tests on peat lands in the Sacramento–San Joaquin Delta showed response to phosphorus.

Regions not responding to phosphorus

Tests in Imperial Valley showed no response to phosphorus, and yields in most cases were increased by nitrogen. Similar tests in the trough of the San Joaquin and Sacramento valleys showed little phosphorus deficiency, and yields were either increased by added nitrogen or failed to respond to any added fertilizers. Similarly, tests in the mountain

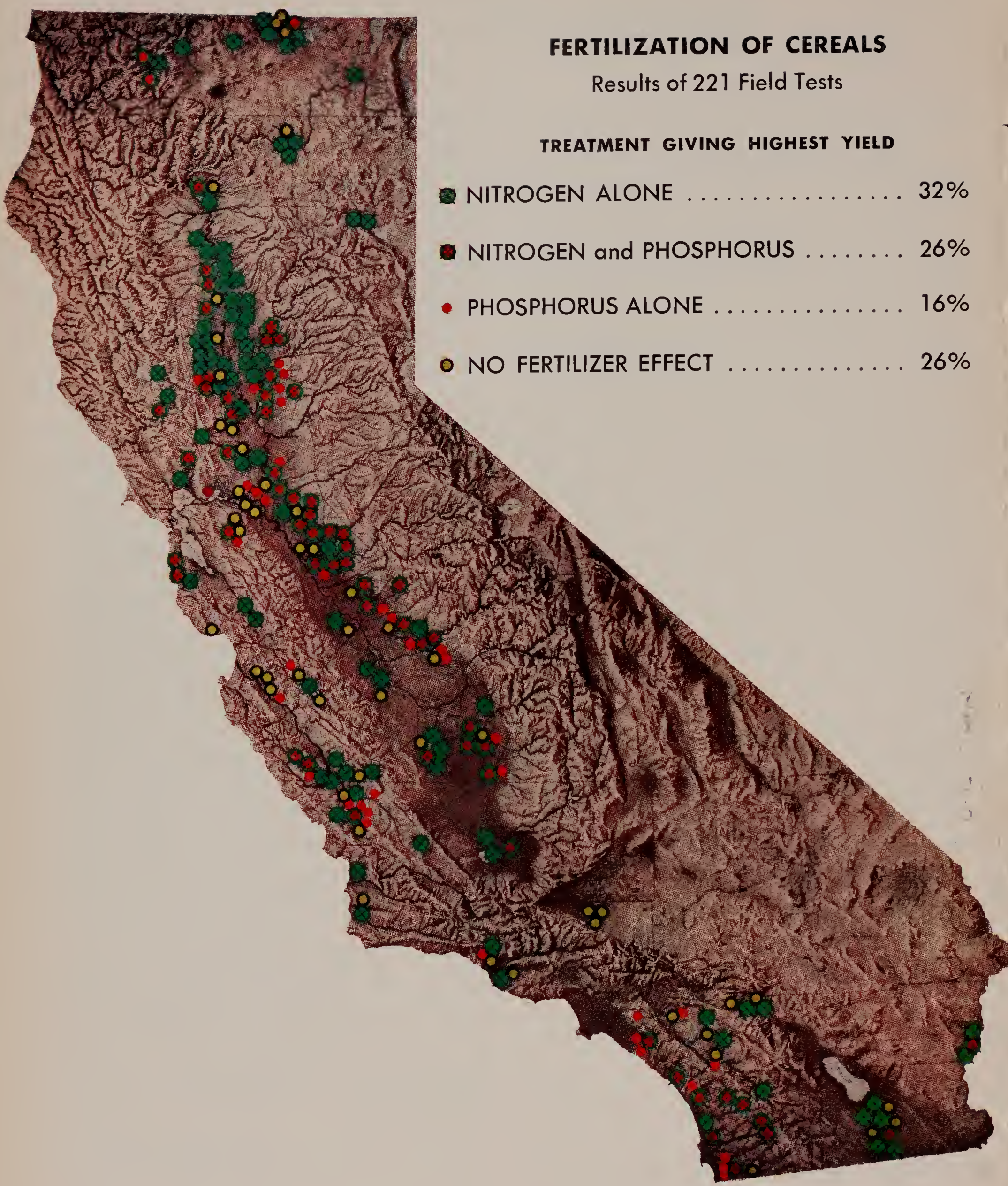


Fig. 2. Map shows proportion of soils found deficient in nitrogen and phosphorus in 38 counties.

valleys of northeastern California rarely showed response to added phosphorus, but usually showed increased yield from nitrogen. Lack of phosphorus response in the Imperial Valley may be attributed to the fact that grain there usually follows crops such as alfalfa or vegetables, which are often heavily fertilized with phosphorus.

What Soil Series and Groups Needed Phosphorus?

In the preceding section it was shown that soils in some physiographic zones of the state usually responded to phosphorus, while others appeared well supplied as judged by field fertilizer tests. Of the 221 tests in this study, 192 were on soils mapped by soil surveys, and the soil series at each location could be identified. These tests, representing 74 different soil series, have been assembled in soil profile groups according to Storie and Weir's (1953) classification of California soils, and the results are summarized in table 1.

Soils of Groups I and II are relatively young soils occurring on recent alluvial fans and flood plains. These soils show slight profile development, being relatively uniform in texture and generally deep and permeable. Only 11 of the 59 tests on soils of this type (19 per cent) showed response to added phosphorus. Typical Group I and II soil series are Columbia, Vina, Greenfield, and Yolo. Phosphorus deficiency was observed on the Arbuckle, Chino, and Egbert series and on some of the calcareous series, such as Cajon, Chino and Adelanto, and Meloland.

Group III soils represent older soils on plains or old alluvial fans. These soils show some clay accumulation at depth, and are not usually so well drained nor permeable as the younger soils of Groups I and II. Eleven of the 36 tests on soils of this group (30 per cent) showed response to added phosphorus. Harrington, Myers, and Gridley are typical series of this group adequately supplied with phosphorus, while some deficiency was observed in tests on the Lockwood, Ducor, and Ramona series.

Group IV soils represent still older soils, usually on old terrace formations or ancient plains, and have a strong accumulation of clay at depth. These soils usually are referred to as "claypan" soils, and are characterized by poor internal drainage, particularly in wet years. Eighteen of the 25 tests on soils of this group (72 per cent) responded to added phosphorus. Corning, Watsonville, and Huerhuero are typical series of this group responding to phosphorus.

Group V soils again represent old soils,

Table 1.—Relation of Soil Profile Group to Response of Grain to Nitrogen and Phosphorus Fertilizers (173 tests on 74 soil series)

Soil profile groups	Number of:		Tests showing response to:				Deficient in:	
	Soil series	Field tests	None	N only	N + P	P only	N	P
			per cent	per cent	per cent	per cent	per cent	per cent
I. Recent alluvial soils	18	38	36	45	8	11	53	19
II. Young alluvial soils	9	21	29	52	14	5	66	19
III. Older alluvial soils	14	36	28	42	8	22	50	30
IV. Claypan soils	13	25	20	8	48	24	56	72
V. Hardpan soils	10	30	10	7	50	33	57	83
VII, VIII, IX. Upland soils	10	23	4	17	44	35	61	79

usually on ancient terraces or old alluvial plains, but characterized by the presence of a cemented hardpan layer, often with some clay accumulation immediately above the hardpan. These soils are often quite shallow because of the hardpan formation below, and tend to become waterlogged in wet years and droughty in dry seasons. Twenty-five of the 30 tests on soils of this group (83 per cent) responded to added phosphorus. San Joaquin and Rocklin are typical series in this group responding to phosphorus.

Groups VII, VIII, and IX represent upland soils developed in place by the weathering of either hard rock or softly consolidated material. This is a broad grouping, including soils of widely differing parent material. Eighteen of the 23 tests on these upland soils (79 per cent) showed response to phosphorus. Linne, Altamont, and Vista are typical soils of this general group.

Phosphorus deficiency was clearly related to soil profile group and series as discussed above and shown in table 1. Most of the irrigated grain is produced on recent or young alluvial soils (Groups I, II, and III) which are relatively well supplied with available phosphorus. Conversely, nonirrigated grain is cultivated principally on older soils occupying terrace positions (Groups IV and V) or on upland soils (Groups VII, VIII, and IX) which commonly are deficient in phosphorus.

No definite relationship between soil group and nitrogen deficiency was observed. The proportion of soils in all groups responding to nitrogen either alone or with phosphorus remained about the same.

The observed fertilizer responses of each of the 74 soil series are shown in Appendix table 2A (pp. 38–39).

Soil Analysis Indicates Need for Phosphorus

Soil analysis offers a satisfactory means of predicting whether or not a soil to be planted with grain needs an application of phosphorus. Subsequent to the field studies on grain fertilization, a study was made of soil samples taken from the sites of the field tests prior to planting and applying the fertilizer materials. Samples from 101 out of the 221 field tests were available for study. These were analyzed for phosphorus, in the laboratory, by several different methods. The water-soluble phosphorus extraction method of Bingham (1949) and the bicarbonate extraction method of Olsen (1954) were the only tests offering promise over the wide range of soils in this study.

Prediction of phosphorus response by water-soluble phosphate extraction

This method gave 92 per cent accuracy of prediction, using a threshold value of 0.4 ppm PO_4 in the 1-to-10 water extract. Results with this method, shown in table 2, indicate the proportion of tests responding to phosphorus over a wide range of soil phosphate values. It will be noted that below 0.1 ppm, all samples were from plots which gave field response to phosphorus application. Between 0.1 and 0.2 ppm, 96 per cent of the samples gave phosphate response. Above 0.4 ppm, only one sample showed field response to phosphorus. Using the 0.4 value as threshold, 52 of the 59 samples in which phosphorus response was predicted actually gave a response, or an accuracy of 88 per cent. Of the values above 0.4, which should not have given a response, only one error was made, for an accuracy

Table 2.—Prediction of Phosphorus Response of Grain by Use of Soil Analysis

Water phosphate extraction				Bicarbonate phosphate extraction			
Range of PO_4 values*	No. of tests	No. of responses to phosphorus	Phosphorus response	Range of PO_4 values†	No. of tests	No. of responses to phosphorus	Phosphorus response
ppm in water			per cent	ppm in water			per cent
0–0.1......	13	13	100	0–0.4......	16	16	100
0.1–0.2......	23	22	96	0.4–0.7......	23	21	91
0.2–0.3......	16	12	75	0.7–1.0......	17	14	82
0.3–0.4......	7	5	71	1.0–1.3......	2	0	0
0.4–0.5......	5	1	20	1.3–1.6......	4	1	25
0.5–0.6......	1	0	0	1.6–1.9......	2	0	0
0.6–0.7......	7	0	0	1.9–2.2......	3	0	0
0.7–0.8......	5	0	0	2.2–2.5......	6	0	0
0.8–0.9......	3	0	0	2.5–2.8......	5	0	0
0.9–1.0......	1	0	0	2.8–3.1......	4	0	0
1.0–1.1......	4	0	0	3.1–3.4......	2	0	0
1.1–1.2......	4	0	0	3.4–3.7......	5	0	0
1.2–1.3......	3	0	0	3.7–4.0......	6	1	17
Over 1.3....	9	0	0	Over 4.0....	6	0	0

* Using 0.4 ppm as threshold:

Below 0.4 $\frac{\text{52 responses}}{\text{59 total}}$ = 88% accuracy

Over 0.4 $\frac{\text{41 no responses}}{\text{42 total}}$ = 98% accuracy

† Using 1.0 ppm as threshold:

Below 1.0 $\frac{\text{51 responses}}{\text{56 tests}}$ = 91% accuracy

Over 1.0 $\frac{\text{53 no responses}}{\text{55 tests}}$ = 96% accuracy.

in this zone of 98 per cent. Some of the tests in which phosphorus response was predicted but not obtained were at relatively dry locations where there was not enough growth to respond to any fertilizer application.

Prediction of phosphorus response by means of bicarbonate extraction

This method gave equally good results. If 1 ppm PO_4 in the soil extract were taken as threshold value (equivalent to 30 pounds P_2O_5 per acre 6 inches), the method would have predicted observed results correctly with 94 of the 101 tests, an over-all accuracy of 93 per cent (table 2). Only two samples in the high-phosphorus range indicated that the field had benefited from added phosphorus. The bicarbonate method is not recommended for use on peat or muck soils because results are erratic and unpredictable.

Soil analysis does not predict how much phosphorus to use

The necessity of adding phosphorus to soils planted to cereals can be predicted quite accurately by soil analysis. No relationship was found, however, between the values attained by either method of analysis and the amount of phosphorus that had to be applied for maximum production. Soil analysis for phosphorus did not predict the intensity of the phosphorus deficiency nor the degree of benefit in production which might be expected on soils classified as phosphorus-deficient.

Soil Analysis Fails to Predict Need for Nitrogen

A study of 122 soil samples from test sites revealed no relationship between response to nitrogen and amounts of either nitrate or ammonia nitrogen present at time of sampling. Supplies of available nitrogen in the soil are subject to drastic changes with moisture and temperature fluctuations. Rapid losses of nitrates may result from leaching or denitrification. On the other hand, high soil temperatures may cause rapid increases of available nitrogen through speedup of decomposition of organic materials. Low temperatures will slow down the nitrification process. As a result, it is hardly unexpected that neither nitrate nor ammonia nitrogen, at planting, was found definitely related to nitrogen supply during the crop season.

Table 3.—Per Cent of Tests Showing Increased Yield from Nitrogen

Irrigation status	Tests showing increase	
	Following cereal or other non-legume	Following legume, fallow, or on an organic soil
	per cent	per cent
Irrigated grain......	69	11
Nonirrigated grain ..	73	49
Average............	72	46

Nitrogen Response Related to Preceding Crop History

The necessity of applying nitrogen to grainland is closely related to cropping history. This relationship is shown in table 3. Need for nitrogen was shown in approximately 72 per cent of tests in which either irrigated or nonirrigated grain followed cereal or other nonlegumes. Since nitrogen responses were seldom observed on organic soils, results from such soils have been grouped with results either on fallow land or where a legume preceded the grain. On such land, fallowed or cropped to legumes the preceding season, 46 per cent of tests responded to nitrogen. There was no clear relationship between preceding crop history and response to added phosphorus.

FERTILIZATION OF NONIRRIGATED GRAIN

Relation of Rainfall and Crop History to Fertilizer Response

Production of grain under nonirrigated conditions is greatly affected by soil moisture and rainfall distribution, as well as by soil management and fertilizer practices. Where rainfall is less than 12 inches, grain is usually grown biennially on land allowed to lie fallow during the preceding season. Where rainfall is over 16 inches, grain is often grown every year on the same land. In the intermediate zone, with rain of 12 to 16 inches, a fallow system is usually employed, but occasionally consecutive grain crops may be grown.

A total of 176 fertilizer tests was run on nonirrigated grain. They showed 28 per cent of soils deficient in both nitrogen and phosphorus, 30 per cent deficient in nitrogen alone, 18 per cent deficient in phosphorus alone, and 24 per cent that did not respond either to nitrogen or phosphorus fertilizers. Thus deficiencies of both nitrogen and phosphorus are common on nonirrigated grainland.

Soil nitrogen was found deficient in 58 per cent of nonirrigated grainland soils.

The available supply from soil organic matter had been reduced by years of continued production. Where annual cropping occurs, crop needs usually exceed natural soil supplies of nitrogen. The supply of available nitrogen may increase during the fallow year through activity of nonsymbiotic nitrogen-fixing organisms and through the slow decomposition of soil organic matter and recent crop residues. Accumulated nitrates may remain for crop use or become lost by leaching, if rainfall is excessive, or by denitrification if the soil becomes waterlogged. Thus, both rainfall and crop sequence may be expected to affect the results of and need for nitrogen fertilization.

Soil phosphorus was found inadequate in 46 per cent of field tests run. The supply of available phosphorus seems most directly related to the chemical nature and age of the soil and probably to the length of time the land has been cropped to grain without phosphorus fertilization. Thus, phosphorus supply is not affected by current soil cropping practices. During the crop year, phosphorus responses may be magnified by cold temperatures during winter months. With warm, spring temperatures, responses may become less evident.

The relationship of rainfall and crop sequence to the frequency of nitrogen response is summarized in table 4. These figures show the proportion of the tests in which nitrogen increased yield. The data include measurements from soils deficient in phosphorus as well as from soils adequately supplied with this nutrient. A response to nitrogen was recorded when the yield from added nitrogen treatments was significantly greater than that from the corresponding treatment without nitrogen. Thus, on high phosphorus soils, a nitrogen response represented yield increases from nitrogen alone. On phosphorus-deficient soils, a nitrogen response represented a yield increase after the initial deficiency of phosphorus had been corrected. Such soils often show little or no effect of nitrogen alone.

An examination of the rainfall effects shows that the likelihood of benefit from nitrogen fertilizer increased as the rainfall became greater. With annual barley, only 20 per cent of the tests showed benefit of nitrogen where rainfall was below 10 inches. In the 10- to 12-inch rainfall group, 46 per cent showed increase, while in the tests with over 12 inches of rain, 96 per cent showed significant benefit of nitrogen fertilization. On fallow barley, only about a third of the tests in which rainfall was below 12 inches showed benefit from nitrogen application, while somewhat over a half showed a nitrogen response when the rainfall was over 12 inches. Similar results were observed on fallow wheat, with 50 per cent of the tests above 10 inches showing benefit from fertilization. With rainfall less than 10

Table 4.—Relation of Rainfall and Crop Sequence to Occurrence of Nitrogen Deficiency of Nonirrigated Grain

Kind of grain culture	No. of tests	Tests responding to nitrogen with seasonal rainfall of:		
		Under 10″	10–12″	Over 12″
		per cent	per cent	per cent
Annual barley	42	20	46	96
Fallow barley	49	30	35	56
Fallow wheat	40	31	50	50
Average total	131	29	43	68

inches, only 31 per cent of wheat tests showed benefit from nitrogen.

Both rainfall and crop sequences affect the likelihood of benefit from nitrogen applications. When land is cropped annually, there is no opportunity for moisture or nitrogen to accumulate. When land is fallowed prior to cropping, moisture may be stored in the soil, and available nitrogen supplies also build up. In addition, the fallow year gives an opportunity for reduction of annual weeds.

It is well known that grain yields are less under drought conditions than when adequate moisture is present. It is also a common observation in California that in years of high rainfall, when soils become waterlogged, grain yields are poorer than when lesser but adequate amounts of rain are evenly distributed throughout the growing season. The effect of excess soil moisture in causing poor grain performance may be explained on the basis either of increased root diseases or loss of available nitrogen through leaching or denitrification. Impaired aeration also has an adverse effect on production.

It would be expected that, under low rainfall conditions, moisture rather than fertility would be the factor limiting yields. With adequate rainfall, fertility may be expected to limit production. The benefit of added nitrogen should become greater as rainfall increases and losses of accumulated nitrogen take place. It is recognized that the distribution of rainfall throughout the growing season may be as important as the total amount during that period. Similarly, the slope, texture, permeability, and water-holding capacity, along with the density of plant population, will influence crop behavior, both during periods of drought and periods of excess rainfall. Recognizing these limitations, attempts were made, as reported in the following sections, to relate total seasonal rainfall, recorded at the nearest weather station, to observed crop behavior and fertilizer response.

Annual Barley

A total of 40 replicated rate tests with barley was carried out on annually cropped grainlands. Twenty-five of these rate tests showed no response to phosphorus (table 5), while 15 showed significant effects of phosphorus, alone or with nitrogen.

Table 5.—Effect of Nitrogen on Yield and Profit from Fertilization (Soils not responding to phosphorus)

Seasonal rainfall		Sig. N* / No. tests	Base yield	Av. increase from:		
Range	Average			N_{15}	N_{30}	N_{45}
inches	inches		lb/A	lb/A	lb/A	lb/A
Below 10	8.71	0/2	743	45	−15	−37
10–12	10.87	2/6	1,871	252	250	181
Over 12	15.99	15/17	1,448	294	527	605

* Sig. N / No. = Number of significant responses to N / Number of tests in each group.

† Average profit = value of increased yield at $2/cwt, less cost of N at 13.3 cents/lb.

‡ Frequency = per cent of tests in which treatment was profitable.

On soils not responding to phosphorus

Two of the 25 tests were in areas where the annual rainfall for the crop season was below 10 inches. The yield without treatment was 743 pounds of barley per acre. The 15-pound nitrogen treatment showed a slight increase of 45 pounds of barley per acre, while the 30- and 45-pound rates showed small decreases. None of these differences with low rainfall was statistically significant at the 5 per cent level.

Six tests in the 10- to 12-inch rainfall group resulted in an average yield of 1,871 pounds without fertilization. In two of the six, yields were significantly increased by the application of nitrogen. In several of the other tests, yields were increased numerically, but the differences were not statistically significant. The average yield increase of all six plots in this rainfall zone was 252 pounds of barley from 15 pounds of nitrogen, with slightly smaller increases where more nitrogen was employed.

Seventeen plots were in the high-rainfall group of 12 inches or more seasonal rainfall. The average recorded rainfall from the nearest official weather stations was about 16 inches. In this group, 15 of the 17 tests showed significant yield increases from the application of nitrogen. The average increase of all tests amounted to 527 pounds per acre from 30 pounds of nitrogen, and 605 pounds per acre where 45 pounds of nitrogen were applied. The 15-pound nitrogen rate was not enough nitrogen for satisfactory production with this amount of rainfall.

Evaluation of results. Results of nitrogen fertilizers on annual barley were evaluated in terms of their dollar value. Profit from fertilization was calculated by deducting the cost of the nitrogen applied from the value of the increased yields of barley. Barley was evaluated at $2 per hundred weight (cwt). Nitrogen costs were established at 13.3 cents per pound. Using this value, 15, 30, and 45 pounds of nitrogen cost $2, $4, and $6, respectively. On this basis it would require 100 pounds of barley to pay for each 15-pound unit of nitrogen applied. It is important to evaluate results of a fertilizer test on the basis of their economic significance in dollar value rather than to rely solely upon statistically significant yield differences. A simple economic relationship has been used here to provide a quick approximation of the value of fertilization.

In the two tests carried out in areas with less than 10-inch rainfall, the yields were not significantly affected, but the losses in operating costs which would have resulted from application of fertilizer material are important economically. Clearly, a hazard of using fertilizer under low rainfall conditions would be the likely loss of $4.30 to $6.74 an acre if 30 to 45 pounds of nitrogen were used.

Results in the 10- to 12-inch rainfall zone show that the average yield increase of 252 pounds per acre from 15 pounds of nitrogen would pay the fertilizer cost of $2 and in addition return a profit of $3.04 per acre. With 30 pounds of nitrogen and no additional yield increase, the

of Annual Barley

Av. profit†/acre, and frequency‡		
N_{15}	N_{30}	N_{45}
−$1.10	−$4.30	−$6.74
0%	0%	0%
3.04	1.00	−2.38
83%	50%	50%
3.88	6.54	6.10
71%	88%	88%

operation would remain profitable, but at the rate of only $1 an acre. If 45 pounds of nitrogen were used, a loss of $2.38 per acre would be sustained.

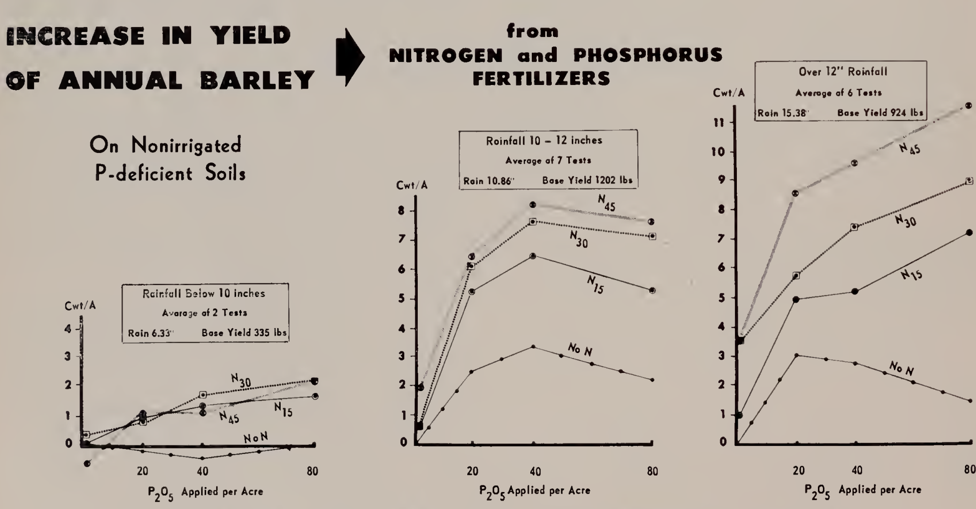
Where annual rainfall was over 12 inches, fertilization was profitable in most cases. With 30 pounds of nitrogen, the value of the increased barley production was $6.54 an acre more than the cost of the fertilizer. Slightly less profit was indicated where 45 pounds of nitrogen were used. In contrast, the 15-pound rate of nitrogen was clearly not enough, and returned an average profit of only $3.88 per acre.

The frequency of profitable response from fertilization is of importance. In the group of tests in the 10- to 12-inch rainfall group, 83 per cent, or five out of six of the tests fertilized with 15 pounds of nitrogen, showed yield values increased enough to pay for the fertilizer and return a profit. The average profit of all six locations was $3.04.

In the over-12-inch rainfall zone, 88 per cent of the tests showed profitable results of fertilization with 30 to 45 pounds of nitrogen. There would seem to be little to justify the use of the higher nitrogen rate on annual barley. If nitrogen were available at 10 cents per pound, the profit per acre would be virtually the same for the 30- and 45-pound rates.

On phosphorus-deficient soils

Fifteen rate tests were carried out on soils responding to phosphorus. Sixteen different treatments were employed, using nitrogen at 0, 15, 30, and 45 pounds per acre, with phosphorus treatments of 0, 20, 40, and 80 pounds P_2O_5 per acre at each level of nitrogen. Results of these tests have been separated on a basis of seasonal rainfall, and are shown in figure 3.



AVERAGE PROFIT PER ACRE AND FREQUENCY OF PROFIT

N Used	No P	P_{20}	P_{40}	P_{80}
None	X	-$2.43 / 0	-$4.78 / 0	-$7.98 / 0
N_{15}	-$1.90 / 0	-2.04 / 0	-3.12 / 0	-6.44 / 0
N_{30}	-3.16 / 0	-4.16 / 0	-4.38 / 0	-7.62 / 0
N_{45}	-7.14 / 0	-5.80 / 0	-7.54 / 0	-9.55 / 0

N Used	No P	P_{20}	P_{40}	P_{80}
None	X	$3.00 / 71%	$2.46 / 57%	-$3.64 / 29%
N_{15}	-$.94 / 29%	6.44 / 100	6.76 / 86	.32 / 43
N_{30}	-2.92 / 14	6.08 / 86	7.08 / 86	2.12 / 57
N_{45}	-2.18 / 29	4.88 / 71	6.30 / 86	1.10 / 43

N Used	No P	P_{20}	P_{40}	P_{80}
None	X	$4.18 / 67%	$1.17 / 50%	-$4.94 / 0
N_{15}	-$.20 / 17%	5.92 / 67	4.52 / 50	4.54 / 67
N_{30}	2.90 / 67	5.56 / 67	6.76 / 100	5.96 / 67
N_{45}	.94 / 50	9.16 / 100	9.28 / 83	9.16 / 67

Fig. 3. Results of 15 rate tests with annual barley on soils responding to phosphorus, segregated on a basis of seasonal rainfall.

The two tests carried out under drought conditions with rainfall of less than 10 inches showed only slight benefit from fertilization. There were slight but significant increases in yield from nitrogen plus phosphorus treatments.

The annual barley tests in the 10- to 12-inch rainfall group showed only slight effects of nitrogen alone, and a moderate response to phosphorus without nitrogen. Where both nutrients were applied, yields were greatly increased. There was, however, little difference among the three rates of phosphorus application. After phosphorus was applied, yields were increased sharply by 15 pounds of nitrogen, with a small additional increase from 30 pounds of nitrogen, but tended to level off with little additional benefit from the 45-pound application.

Results of six tests in areas with higher rainfall (average, 15.38 inches) show quite different behavior at most locations. Yields without fertilization were 924 pounds per acre as compared with 1,202 in the 10- to 12-inch zone. Maximum increases from use of fertilizers were slightly greater. Nitrogen treatments without phosphorus gave definite increases in yields. Applications of phosphorus alone increased yields somewhat, as with 10 to 12 inches of rainfall, but the greatest effects of fertilization were apparent where both nitrogen and phosphorus were used. Here, yields increased with each successive increment of nitrogen. Yields with 80 pounds P_2O_5 averaged somewhat greater than those from either 20- or 40-pound rates, provided nitrogen was added.

Evaluation of results. On phosphorus-deficient soils, evaluation was made in terms of dollar value of increased production, less cost of the fertilizer materials used. As before, increase in yield of barley was evaluated at $2 per cwt, nitrogen cost at 13.3 cents, and P_2O_5 at 10 cents, per pound. Results of the evaluation study are shown in the companion tables below each chart in figure 3.

In tests under drought conditions (rainfall 6.33 inches), none of the fertilizer treatments gave responses in yield of sufficient value to pay the cost of the fertilizer materials.

The seven tests in the 10- to 12-inch rainfall group reveal that the application of nitrogen alone did not produce enough additional barley to pay for the cost of the fertilizer, and a net loss was sustained in all such treatments. Where phosphorus was applied alone, the 20-pound rate gave a profit of $3 an acre, with a $2.46 profit from 40 pounds of phosphorus and a loss of $3.64 where 80 pounds were used. The combination treatments show some interesting results. With 20 pounds of phosphorus and 15 pounds of nitrogen, an average profit of $6.44 over cost of fertilizer was obtained. At this same phosphorus rate, higher rates of nitrogen, although they produced slightly higher average yields, gave lower net returns per acre. In other words, the cost of the added nitrogen was greater than the value of the additional production. All the nitrogen treatments with 40 pounds of phosphorus gave profits virtually the same as those from the $N_{15}P_{20}$ treatment. Profits from the nitrogen treatments at the P_{80} level were much reduced. There was no significant benefit from adding the last 40 pounds of phosphorus, but there was an additional charge of $4 per acre. Numerically, the highest yields were obtained from the $N_{45}P_{40}$ treatment. Here the increase in yield was 815 pounds per acre, as compared with 522 pounds from the $N_{15}P_{20}$ treatment. The $N_{45}P_{40}$ treatment, which cost $10, showed a profit of $6.30, while the $N_{15}P_{20}$ treatment, which cost only $4 per acre, gave a profit of $6.44 per acre.

In evaluating tests of the higher rainfall group, the combination nitrogen and phosphorus treatments with 45 pounds of nitrogen gave the highest average profits per acre. There was no economic benefit, however, in applying more than 20 pounds of phosphorus. While yields

were increased to some degree by more phosphorus, the additional return was just about sufficient to pay for the cost of the extra phosphorus used. An average profit of $9.16 per acre was obtained from the $N_{45}P_{20}$ treatment, which cost $8 per acre.

In the companion tables shown below each set of graphs in figure 3, percentage figures are also listed, showing the frequency of profit. In the 10- to 12-inch rainfall zone, for instance, the $N_{15}P_{20}$ treatment was profitable in all seven tests, for an average profit of $6.44 per acre. A frequency value of 100 per cent is indicated. The $N_{15}P_{80}$ treatment was profitable in three of the seven tests, showing a loss in the remaining four. A frequency value of 43 per cent is indicated, along with the average profit of 32 cents per acre for this treatment. In the higher rainfall zone, the $N_{45}P_{20}$ treatment was profitable in all six tests, for a frequency value of 100 per cent and an average profit of $9.16. The $N_{45}P_{80}$ treatment showed a very good profit in four of the six tests, while in the other two a slight loss was sustained. The average profit per acre remained about the same as when more phosphorus was used, but the frequency of a profitable response was reduced from 100 per cent to 67 per cent as the phosphorus rate increased from 20 to 80 pounds per acre.

Fallow-cropped Barley

A total of 41 replicated rate tests was carried out with biennially cropped barley on land which had been allowed to lie fallow. Twenty-six of these tests showed no measurable response to phosphorus, while 15 gave significant increases in yield from phosphorus alone or in combination with nitrogen.

On soils not responding to phosphorus

Results of these 26 tests are summarized in table 6. The tests in this group are listed in separate rainfall classes, determined by the seasonal rainfall recorded by the nearest official weather stations.

Eight tests were in areas that had seasonal rainfall of less than 10 inches. Three of these showed significant *reduction* where nitrogen was applied, and only three showed a significant improvement in production. The average of all eight tests indicates a small increase in yield from 15 pounds of nitrogen, but decreases in yield where 30 or 45 pounds of nitrogen were applied.

Eighteen tests were run in areas of

Table 6.—Effect of Nitrogen on Yield and Profit from Fertilization (Soils not responding to phosphorus)

Seasonal rainfall		Sig. N*	Base yield	Av. increase from:		
Range	Average	No. tests		N_{15}	N_{30}	N_{45}
inches	inches		lb/A	lb/A	lb/A	lb/A
Below 10	9.00	3/8	1,547	60	−54	−71
Over 10	14.43	5/18	1,734	130	162	174

$$* \frac{\text{Sig. N}}{\text{No.}} = \frac{\text{Number of significant responses to N}}{\text{Number of tests in each group}}.$$

† Average profit = value of increased yield at $2/cwt, less cost of N at 13.3 cents/lb.

‡ Frequency = per cent of tests in which treatment was profitable.

over 10 inches of rainfall. The average rainfall for this group was 14.43 inches. Five of the 18 showed statistically significant increases in yield from added nitrogen. The average yields increased as more nitrogen was applied, with the highest yields from 45 pounds of nitrogen.

Evaluation of results. The same method was used as that employed for annual barley. The increased production due to fertilization was evaluated at $2 per cwt, and the nitrogen used was charged off at 13.3 cents per pound.

All fertilizer treatments lost money where the rainfall was less than 10 inches since none of the nitrogen treatments produced enough extra grain to pay for the fertilizer. The loss figures increased progressively as more was "charged" for nitrogen.

In the group of tests with rainfall over 10 inches, the average yield increase from 15 pounds of nitrogen was sufficient to pay the cost of the fertilizer and return a net profit of 60 cents per acre. At 30 and 45 pounds of nitrogen, the losses from the fertilizer application were 76 cents and $2.52, respectively.

It appears that when barley land lies fallow for the season prior to cropping, available nitrogen tends to build up in the soil. As a result, the likelihood of obtaining profitable responses from the use of nitrogen fertilizers is limited. The frequency of benefit from added nitrogen increases somewhat as rainfall becomes greater. The figures representing the frequency or likelihood of obtaining a profitable response from added nitrogen are also listed in table 6 below the average profit for each treatment. The one "profitable" treatment was 15 pounds of nitrogen in the high rainfall group of samples. Here 50 per cent of the tests had yield increases of greater value than the fertilizer cost.

Greater benefit of nitrogen fertilizer may be expected where summer weeds such as morning glory are allowed to grow during the fallow period. Similarly, nitrogen benefit on fallow land may be greater where a volunteer crop of grain is grazed in the winter and spring prior to initiation of fallow. Similar need for nitrogen is observed where a considerable volume of weeds and volunteer grain is plowed under late in the spring, followed by insufficient rain to permit crop residues to be decomposed before fall planting. Under such conditions the system of culture may hardly be described as one of fallow, and the results of nitrogen application may approach those obtained with annual cropping.

of Fallow Barley

Av. profit†/acre, and frequency‡		
N_{15}	N_{30}	N_{45}
−$0.80	−$5.08	−$7.42
38%	38%	25%
0.60	−0.76	−2.52
50%	33%	22%

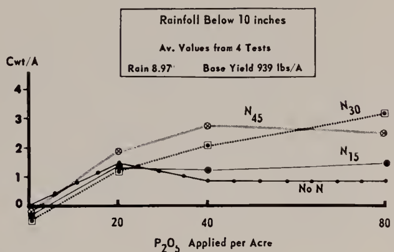
On phosphorus-deficient soils

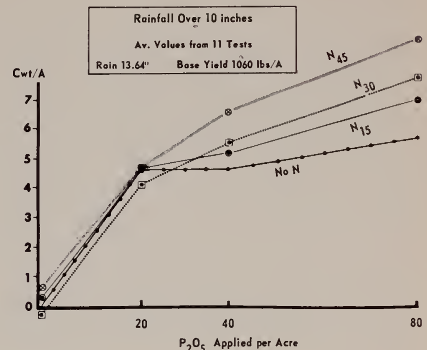
These tests were carried out under a wide range of rainfall conditions, from a low of 7.08 inches to a high of 23.1 inches. In every instance there were significant yield increases from phosphorus alone or from nitrogen-phosphorus combination treatments. The results of 15 of these tests carried out in 1949 and 1950, with standardized fertilizer treatments, are shown in figure 4, segregated on the basis of the seasonal rainfall.

Four tests were carried out in areas with seasonal rainfall below 10 inches. Drought conditions prevailed, and yield increases as a result of fertilization were small. It will be noted that nitrogen alone

INCREASE IN YIELD OF FALLOW BARLEY from PHOSPHORUS and NITROGEN FERTILIZERS

On Nonirrigated P-deficient Soils





AVERAGE PROFIT PER ACRE AND FREQUENCY OF PROFIT

N Used	No P	P_{20}	P_{40}	P_{80}
None		\$ .68 / 75%	-\$2.42 / 25%	-\$6.38 / 0
N_{15}	-\$2.70 / 25%	-1.18 / 25	-3.92 / 0	-7.16 / 0
N_{30}	-4.86 / 0	-3.56 / 0	-4.04 / 0	-6.04 / 0
N_{45}	-5.32 / 0	-4.24 / 0	-4.70 / 0	-9.30 / 0

N Used	No P	P_{20}	P_{40}	P_{80}
None		\$7.16 / 91%	\$5.28 / 82%	\$3.38 / 64%
N_{15}	-\$1.30 / 27%	5.24 / 82	4.44 / 73	3.86 / 64
N_{30}	-4.38 / 9	2.22 / 64	3.12 / 55	3.44 / 64
N_{45}	-4.84 / 9	1.28 / 36	3.12 / 55	1.94 / 45

Fig. 4. Results of 15 rate tests with fallow barley on soils responding to nitrogen and phosphorus, segregated on a basis of seasonal rainfall.

had little or no effect, and that average yields were increased about 136 pounds per acre by 20 pounds phosphorus. Nitrogen applications with phosphorus increased yields significantly in only one of the four tests, but there were slight numerical increases in the other three tests when nitrogen treatments are compared with the corresponding straight phosphorus applications.

Eleven tests were in areas of more than 10 inches seasonal rainfall. In this group of tests the most striking features were the increases in yield from applications of phosphorus alone. An average of 459 pounds of barley was produced from an application of 20 pounds of phosphorus. Higher rates rarely caused any significant additional increase. In eight of the 17 tests there were significant effects of nitrogen after phosphorus applications had been made. In no case were there significant effects of nitrogen without phosphorus. While nitrogen with phosphorus increased yields 73 per cent of the time, only in tests under the higher rainfall conditions and with high phosphorus were there differences clearly in favor of the higher nitrogen rates.

Evaluation of results. Results were evaluated as the dollar value of the increased production less the cost of the fertilizers applied. The average profits for each of the fertilizer treatments are shown in the companion tables below the graphs in figure 4. Below the profit figure a percentage is listed, indicating the frequency of profit or proportion of profitable tests.

The most significant fact is that the 20-pound phosphorus treatment was profitable in nearly every test regardless of rainfall.

A small but profitable return was ob-

tained from 20 pounds of phosphorus under low rainfall conditions in three of the four tests conducted. All other treatments showed a loss. Under conditions of low rainfall on phosphorus-deficient, fallow lands, a light application of phosphorus alone would seem most likely to succeed.

Profits in the group of tests with 10 or more inches of rainfall were greatest from the light phosphorus applications. Here an average profit of $7.14 per acre was obtained from an application of 20 pounds phosphorus, costing only $2. With 10 of the 11 plots profitable, a frequency value of 91 per cent is indicated for this treatment. Higher rates of phosphorus alone showed less average profit since the cost of fertilizer increased with no appreciable improvement in production. The addition of nitrogen to phosphorus resulted in decreased profit per acre. All of the nitrogen plus phosphorus treatments were profitable. The average profit and frequency of profitable response decreased as higher rates of nitrogen were employed. None of the straight nitrogen treatments was profitable, and the loss became greater the more that nitrogen was applied.

Several tests were carried out in 1947 and 1948 on "fallow lands" in areas infested with morning glory or other summer weeds. At such locations, striking and highly profitable yield increases were obtained from 40 pounds of nitrogen with 40 pounds of phosphorus. Yields of these nitrogen plus phosphorus treatments were 400 to 600 pounds more than with phosphorus alone. It is clear that, while barley was grown biennially at these locations, a system of true fallow did not exist. The results are similar to those reported in the preceding section under annually cropped barley. The growth of morning glory or other summer weeds prevents build-up of available nitrogen during the "fallow" year. An additional observation may be made that some acutely phosphorus-deficient claypan soils require 40 to 80 pounds of P_2O_5 to correct the phosphorus deficiency.

Fallow-cropped Wheat

Forty-one replicated tests with various rates of nitrogen and phosphorus were carried out on fallow-cropped wheatland. Nineteen of these showed no benefit from phosphorus, while 22 gave significant benefits from the addition of phosphorus alone or of nitrogen-phosphorus material. Fertilizer tests with wheat represent slightly different areas of the state than do those for barley. Rainfall in the fallow wheat areas is somewhat less than in areas commonly used for barley.

On soils not responding to phosphorus

Results of the 19 tests in which phosphorus was not effective are summarized in table 7. The results have been grouped on the basis of rainfall, listing together tests in areas with less than 10 inches of rain, and those in areas where more than 10 inches fell during the growing season. In nearly every test the measured yields were increased numerically by nitrogen applications. In many of the tests, however, particularly where rainfall was low, the yield increases were not statistically significant. Wheat produced under spring drought conditions was often somewhat "pinched," but not light and chaffy as is barley following nitrogen applications which stimulate more vegetative growth than may mature with limited soil moisture.

In the rainfall group below 10 inches, only one of the four tests showed a significant yield increase from nitrogen. In the higher rainfall group, however, 10 out of 15 (67 per cent) showed significant effects of nitrogen.

Evaluation of results. Fallow wheat fertilizer tests were evaluated by the same method employed for barley. With wheat, however, the increase was evaluated at $3 per cwt, which required only 67 pounds of wheat to pay for each 15

Table 7.—Effect of Nitrogen of Yield and Profit from Fertilization of (Soils not responding to phosphorus)

Seasonal rainfall		Sig. N*	Base yield	Av. increase from:		
Range	Average	No. tests		N_{15}	N_{30}	N_{45}
inches	inches		lb/A	lb/A	lb/A	lb/A
Below 10.........	7.89	1 / 4	788	111	59	58
Over 10..........	14.02	10 / 15	1,163	182	253	232

* $\frac{\text{Sig. N}}{\text{No.}} = \frac{\text{Number of significant responses to N}}{\text{Number of tests in each group}}$.

† Average profit = value of increased yield at $3/cwt, less cost of N at 13.3 cents/lb.

‡ Frequency = proportion of tests in which each treatment was profitable.

pounds of nitrogen used. In the low-rainfall zone, the average effect of the 15-pound nitrogen treatment was to increase yields 111 pounds and show a net profit of $1.33 per acre. Higher rates of nitrogen did not increase yields enough to pay for the fertilizer used.

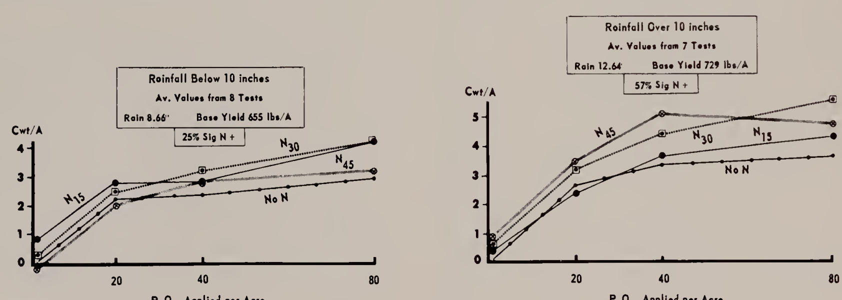
With more than 10 inches of rain, both 15- and 30-pound nitrogen rates gave average profits of about $3.50 per acre.

On phosphorus-deficient soils

Seasonal rainfall varied from a low of 6.30 to a high of 15.39 inches. In every

INCREASE IN YIELD OF FALLOW WHEAT from PHOSPHORUS and NITROGEN FERTILIZERS

On Nonirrigated P-deficient Soils



AVERAGE PROFIT PER ACRE AND FREQUENCY OF PROFIT

N Used	No P	P_{20}	P_{40}	P_{80}
None		$4.45 100%	$2.90 75%	$ .79 63%
N_{15}	$ .34 50%	4.46 75	2.49 75	2.45 63
N_{30}	-3.25 25	1.44 38	1.45 63	.66 50
N_{45}	-6.39 0	-2.00 25	-1.63 25	-4.67 25

N Used	No P	P_{20}	P_{40}	P_{80}
None		$7.93 100%	$6.14 100%	$2.98 86%
N_{15}	-$ .71 43%	3.20 57	5.07 86	3.23 71
N_{30}	-2.44 14	3.84 57	5.41 71	4.80 57
N_{45}	-3.49 14	2.47 43	5.51 71	.25 57

Fig. 5. Results of 15 rate tests with fallow wheat on soils responding to phosphorus, segregated on a basis of seasonal rainfall.

Fallow-cropped Wheat

Av. profit†/acre, and frequency‡		
N_{15}	N_{30}	N_{45}
$1.33	−$1.23	−$3.26
50%	25%	0%
3.46	3.59	0.96
67%	80%	47%

case there were significant increases in yield from phosphorus alone or in combinations with nitrogen. The results of 15 tests carried out in 1949 and 1950 with standardized fertilizer treatments are shown in figure 5. As before, tests were segregated on the basis of rainfall.

Eight tests were conducted at locations where seasonal rainfall was below 10 inches. Responses to fertilization in this group were primarily to phosphorus, with only two of the eight tests showing significant effects of nitrogen added with phosphorus.

Yields of wheat were increased an average of 215 pounds per acre with application of 20 pounds of phosphorus, with slight additional increases at higher rates. These values are about twice the yield increases observed with barley under low-rainfall conditions. Increases attributed to nitrogen additions are small, with no observed differences among the three rates of nitrogen employed.

Seven tests were with rainfall in excess of 10 inches. In this group, again, the most striking features were the benefits from phosphorus alone. Yields were increased 265 pounds per acre by 20 pounds of phosphorus, with small additional increase where 40 and 80 pounds were used. Nitrogen alone had very little effect, but the addition of nitrogen to phosphorus increased yields in four of the seven tests in this group. Thirty and 45 pounds of nitrogen applied with phosphorus gave consistently higher yields than did the 15 pounds of nitrogen at the same phosphorus level.

Evaluation of results. These tests were also evaluated on the basis of the net value of the increased yield after deducting the cost of the fertilizer. Average profits for each of the fertilizer treatments are shown in the companion tables below each of the graphs in figure 5. Also listed are frequency-of-profit percentages indicating the proportion of profitable tests for each of the treatments.

It is significant that the 20-pound phosphorus treatment was profitable in every test in both rainfall groups.

Data from the low rainfall group showed maximum profit of $4.45 per acre with 20 pounds of phosphorus. Applications of 40 and 80 pounds P_2O_5 applied alone resulted in diminished profits per acre and a lesser proportion of profitable tests. The use of 15 pounds of nitrogen with 20 pounds of phosphorus gave almost the same average profit per acre as did both the 20-pound rates of phosphorus alone. Higher rates of nitrogen with phosphorus gave greatly diminished profits and losses in every instance in which 45 pounds of nitrogen were used.

Results of the group of tests in areas where seasonal rainfall was over 10 inches were similar, but benefits of fertilization were considerably greater. The 20-pound phosphorus treatment was profitable in every case, and returned an average net profit of $7.93 after deduction of the fertilizer cost of $2. Results from the 40-pound application rate of phosphorus were profitable in every case, but the net profit was slightly less. The 80-pound rate, which gave little additional yield increase, remained profitable, but the net profit was reduced to slightly under $3 per acre because of the additional expense of unneeded material. Many of the nitrogen plus phosphorus combination treatments gave an average return considerably greater than the cost

of the materials. In most instances, however, the indicated profit was materially less and the frequency of profit in all cases decreased as nitrogen rates were increased. The use of nitrogen alone on these phosphorus-deficient soils resulted in losses at every rate of application.

Data described above would indicate no economic advantage to adding supplemental nitrogen to straight phosphorus treatments where good practices are followed during the fallow period. Results of seven other tests carried out in 1947 and 1948 indicate the same conclusion. However, in cases where summer weeds have not been controlled, or in situations where previous crop residues are turned under late in the spring, applications of nitrogen with phosphorus may be desirable.

FERTILIZATION OF IRRIGATED GRAIN

Irrigated grain is usually grown in valley lands on soils of recent or young alluvial fans or on soils occupying basin positions in the valleys of the state. Grain is often produced on land used for other, more intensive crops. Substantial amounts of commercial fertilizer may be applied, either to grain or to other crops in the rotation.

What Fertilizers Increase Yields of Irrigated Grain?

A total of 43 replicated rate tests, each with four rates of nitrogen and phosphorus, was carried out. Twenty-seven of these were on irrigated barley, 15 with irrigated wheat, and one with oats. Thirty-one per cent of these tests showed no response to fertilization; 11 per cent showed a response to phosphorus but not to nitrogen; 40 per cent gave yield increase from nitrogen alone; while in 17 per cent of the cases both nitrogen and phosphorus were required for maximum yields. Combined results show that 28 per cent of the tests were on soils responding to phosphorus, while in 57 per cent of the tests the soils were deficient in nitrogen.

Relation of Preceding Crop History to Fertilizer Response

The preceding crop history and nature of the soil are important in predicting the necessity of adding nitrogen in the production of irrigated grain. Thirteen of the tests followed a leguminous crop or were on organic soils. Of this group, only 11 per cent showed benefit from added nitrogen. In contrast, in the group of 30 tests following cereal or other nonleguminous crops, 69 per cent benefited from nitrogen fertilizer. There was no observed relationship between crop history and necessity of phosphorus application.

In cases where considerable residual nitrogen remains from a preceding crop, or where high nitrogen applications have been made, excessive vegetative growth may be stimulated. This can result either in lodging or delayed maturity. When lodging occurs early, yields may be reduced through failure of the grain to fill. Disease may also be increased on lodged grain.

Results of Fertilizer Tests with Barley and Wheat

In the sections that follow, results of the nitrogen and phosphorus rate tests

Table 8.—Effect of Nitrogen on Yields of Irrigated Grain (Soils not responding to phosphorus)

Previous cropping	Sig. N* / No. tests	Base yield	Average increase from:				Average profit† or loss/acre, and frequency‡			
			N_{15}	N_{30}	N_{45}	N_{80}	N_{15}	N_{30}	N_{45}	N_{80}
		lb/A	lb/A	lb/A	lb/A	lb/A				
Irrigated Barley										
Cereal or other nonlegume.....	10/16	3,291	440	513	683	940	$6.80 / 73%	$6.26 / 88%	$7.66 / 73%	$8.16 / 43%
Legume, fallow, or on organic soil.	0/3	3,116	−218	+41	−344	..	−6.36 / 0%	−3.18 / 0%	−12.88 / 0%	....
Irrigated Wheat										
Cereal or other nonlegume.....	7/8	1,859	171	654	767	684	$3.13 / 71%	$15.62 / 83%	$17.01 / 88%	$9.88 / 67%
Legume, fallow, or on organic soil.	0/3	1,811	−33	−49	+167	...	−2.99 / 0%	−3.47 / 33%	−0.99 / 33%	.....

$$* \frac{\text{Sig. N}}{\text{No.}} = \frac{\text{Number of significant responses to N}}{\text{Number of tests in each group}}.$$

† Average profit = value of increased yield at $3/cwt, less cost of N at 13.3 cents/lb.

‡ Frequency = proportion of tests in which each treatment was profitable.

are presented and evaluated both on the basis of yield increases and of profit from the use of fertilizer. In making the latter calculations the increased production from fertilization was given a value of $2 per cwt for barley and $3 per cwt for wheat. Profits per acre for fertilization were calculated by deducting the cost of the nitrogen applied at 13.3 cents per pound and the phosphorus at 10 cents per pound P_2O_5 applied per acre. The value remaining was tabulated as profit, and used as a means of determining how much fertilizer may be economically used.

On soils not responding to phosphorus

Results of 29 rate tests with irrigated grain on soils showing no benefit from added phosphorus are summarized in table 8. Tests with both barley and wheat were divided on the basis of preceding crop history. Those following cereal or other nonlegumes were put into one group, while those tests either preceded by a legume or a period of fallow, or located on organic soil were grouped in the second class. Since no significant effect of phosphorus was shown in any of these tests, the results are tabulated as nitrogen rate experiments.

Yields of grain after cereal or other nonlegumes. Yields of grain after cereal or other nonlegumes were usually increased by nitrogen applications. Highest average barley yields were obtained with 80 pounds of nitrogen, but 45 pounds per acre gave nearly as great an average profit per acre as did the higher amount. Frequency of profitable response to nitrogen also is indicated in table 8. These values represent the proportion of individually profitable tests at each nitrogen level. Thus, at 45 pounds of nitrogen, 11 of 15 (73 per cent) tests were profitable (average profit of all 15 tests, $7.66), while in four tests the value of extra barley was less than the cost of nitrogen used. The yield figures with 80 pounds nitrogen were obtained from only seven tests. Three of these gave very high individual profits because of acute nitrogen deficiency, while in the other four tests small "losses" resulted. The average "profit" was $8.16 per acre, but frequency of profit was only 43 per cent. From these results it would appear that treatments of 30 to 45 pounds nitrogen per acre would most likely represent the desirable amount of nitrogen to apply. Results of eight wheat tests following cereal or other nonlegumes were similar to those for barley, with maximum profit and frequency of profit from 45 pounds of nitrogen per acre.

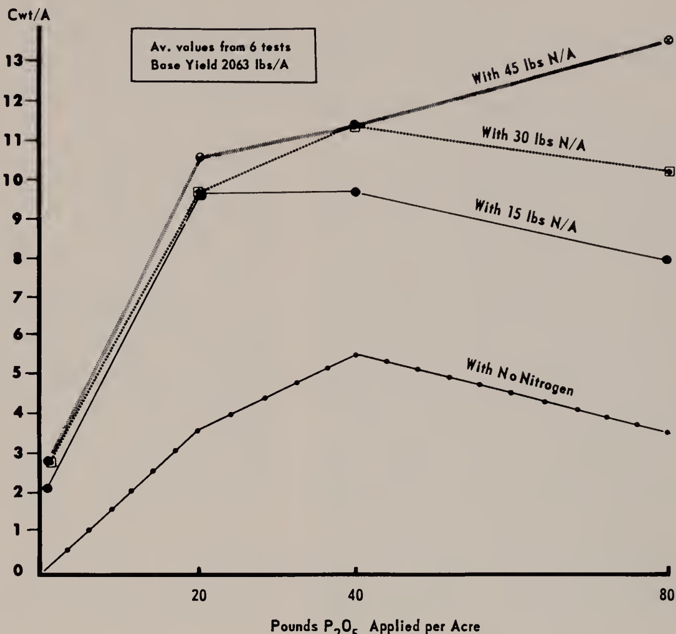
Yield after legume or on organic soils. Yield of grain either following a legume or on organic soils was quite different. Neither barley nor wheat showed significant response to nitrogen. The use of unneeded nitrogen on such soils, however, would have resulted in highly important economic losses of $3 to $13 per acre, with barley, and from $1 to $3.50 in the case of wheat.

On phosphorus-deficient soils

Ten rate tests were conducted on irrigated soils deficient in phosphorus. As before, results were grouped on the basis of preceding crop and nature of the soil. The three wheat tests were either on organic soils or followed a leguminous crop. Six of the seven barley tests followed cereal or nonlegumes on mineral soils, with only one on an organic soil.

Effects of nitrogen and phosphorus on yield of barley following a cereal or nonlegume. These effects are shown graphically in figure 6. The average yield increases from various amounts of nitrogen and phosphorus are plotted out. The average profit per acre and frequency of phosphate response for each of the 15 fertilizer treatments are listed in the diagram below the chart. It will be noted that yields were increased by phosphorus alone, but the greatest production was obtained where both ni-

INCREASE IN YIELD OF IRRIGATED BARLEY from use of P and N FERTILIZERS on P-DEFICIENT SOILS



PROFIT PER ACRE AND FREQUENCY OF PROFIT
From Use of Phosphorus and Nitrogen

N Used	No P	P_{20}	P_{40}	P_{80}
None		\$4.98 67%	\$7.06 50%	-\$ .64 50%
N_{15}	\$2.42 67%	15.14 100	13.40 83	5.66 67
N_{30}	1.50 67	13.02 100	14.76 83	8.16 67
N_{45}	- .32 33	13.08 100	12.72 100	12.96 100

Fig. 6. Results of six rate tests with irrigated barley following a cereal or nonlegume, on mineral soils.

Table 9.—Effect of Phosphorus on Yield of Irrigated Grain on Soils Deficient in Phosphorus Either Following Legume or on Muck Soil

Kind of grain	Base yield	Increase due to:			Av. profit*/acre from:		
		P_{20}	P_{40}	P_{80}	P_{20}	P_{40}	P_{80}
	lb/A	lb/A	lb/A	lb/A			
Barley (1 test)..........	3,805	383	418	311	$5.66	$4.36	....
Wheat (3 tests)..........	3,176	302	473	536	7.06	10.19	$8.08

* With wheat at $3/cwt, barley at $2/cwt, less P_2O_5 at 10 cents/pound.

trogen and phosphorus were used. With 15 and 30 pounds of nitrogen, the curves reach their highest point at 20 to 40 pounds of P_2O_5 per acre. Where 45 pounds of nitrogen were used, the greatest average yield was obtained with 80 pounds of phosphorus. The maximum average profit per acre was obtained from 15 pounds of nitrogen and 20 pounds of phosphorus. The $N_{30}P_{40}$ treatment gave a profit of about the same magnitude. All combined nitrogen-phosphorus treatments of P_{20} and P_{40} were profitable at all rates of nitrogen added. The profit figures, however, would indicate little advantage to using over 15 to 30 pounds of nitrogen. In cases where nitrogen has been depleted by several successive crops of grain, higher rates of nitrogen would be indicated. There would seem to be no reason for using over 40 pounds of P_2O_5 per acre.

On organic soils or following a legume. In these situations, irrigated grain showed little benefit from added nitrogen, and principal benefits were from phosphorus. One barley and three wheat tests were available for comparison.

Yield of irrigated barley on Egbert muck is listed in table 9. In this single test, phosphorus increased yields by roughly 10 per cent. There was no consistent nor significant effect of added nitrogen alone or with phosphorus. On this soil, 20 pounds P_2O_5 per acre gave a profit of $5.60 per acre for an expenditure of only $2 per acre. It would be expected that in some of the valleys of California where low spring temperatures prevail, some nitrogen would be desirable on similar phosphorus-deficient organic soils.

Irrigated wheat results were similar to those for barley. In three tests there was no significant effect of nitrogen alone or with phosphorus. Applications of phosphorus, however, were all profitable, with the highest profit from 40 pounds P_2O_5 of $10.10 per acre for a cost of only $4 per acre. In one test in the Blythe area, where wheat was planted after plowing down an old stand of alfalfa, yields were not improved by either nitrogen or phosphorus alone, but a good response was observed when both were applied. The $N_{30}P_{80}$ treatment made a "profit" of $10.26 per acre from a $12 per acre fertilizer treatment.

EFFECTS OF FERTILIZATION ON GRAIN QUALITY

The factors defining quality in cereal grains vary, depending on how the grains are to be used. Most California grain is used for feeding livestock and poultry. A lesser proportion is used for direct human consumption, primarily in flour, breakfast cereals, malt products, and beer. Only some of the general aspects of grain quality will be considered in this discussion.

Test Weight of Grain

Test weight per bushel is an important quality factor in assigning a grade to a given lot of grain under official grain standards of the United States. Test weight is the weight of the volume of grain required to fill a standard bushel measure.

The test weight per bushel of barley is related to the total digestible nutrients in the grain. Low test weight barley is bulkier, has a higher fiber content, and is therefore lower in total digestible nutrients than is barley weighing the standard 48 pounds per bushel. The test weight of barley is a part of the official grade designation and helps determine market value. Maltsters prefer a plump barley with test weight of 46 to 50 pounds per bushel for six-row barley, and 50 to 52 pounds for two-row barley such as Hannchen.

Test weight measurements were made on barley samples taken from fertilizer tests in 1947 and 1948 to determine to what extent test weight of barley was influenced by nitrogen and phosphorus application. Considerable variations in test weight were encountered. These were affected by variety and climatic conditions, as well as by fertility.

The effect of nitrogen fertilizer on the test weight of barley is closely related to soil moisture supply as shown in table 10. With irrigated barley, adequately supplied with moisture, nitrogen alone or with phosphorus had no effect on test weight. Barley on fallow-cropped land with adequate soil moisture was likewise unaffected in test weight by nitrogen fertilization, although the weight values were somewhat lower than those obtained from irrigated barley.

Under conditions of spring drought, the use of nitrogen on soils with adequate

Table 10.—Effect of Cropping System and Nitrogen and Phosphorus Fertilization on Test Weights of Barley on Soils with Adequate Phosphorus

Cropping conditions	Test weights of barley with nitrogen applied at:			
	N_0	N_{15}	N_{30}	N_{45}
Irrigated barley (adequate moisture):	lb/bu	lb/bu	lb/bu	lb/bu
N alone	50.8	51.0	51.2	51.5
N + P_{80}	50.8	51.5	52.0	51.4
Fallow-cropped barley (adequate moisture):				
N alone	46.3	46.3	46.0	46.2
N + P_{40}	45.9	46.2	46.5	46.8
Fallow-cropped barley (spring drought):				
N alone	45.3	44.4	44.7	43.6
N + P_{40}	45.7	44.2	44.6	43.8

Table 11.—Test Weights of Barley Grown on Soils with Acute Phosphorus Deficiency

Nitrogen applied	Test weights of barley with phosphorus applied at:			
	P_0	P_{10}	P_{20}	P_{40}
lb/A	lb/bu	lb/bu	lb/bu	lb/bu
0.....	45.3	46.9	46.8	47.6
10.....	45.3	45.8	46.5	46.4
20.....	43.3	44.9	45.4	45.7
40.....	42.7	43.6	43.7	44.9

phosphorus tended to reduce the test weight. Under these conditions addition of phosphorus had no effect. Where nitrogen was applied in amounts sufficient to cause greatly increased vegetative growth—followed by acute spring drought conditions—both the yield and the test weight of barley were reduced.

On soils of acute phosphorus deficiency, test weight was increased by phosphorus fertilization, but was reduced where nitrogen was added. The average test weights of barley harvested from four such locations are shown in table 11. The increases in test weight from use of phosphorus amounted to 4.4 pounds per bushel in some cases, while the reductions in test weight due to nitrogen amounted to as much as 4.5 pounds per bushel under extreme conditions. The increases in test weight attributed to phosphorus are probably related to barley's more extensive root system which enables it to seek moisture at deeper levels.

Protein Content of Grain

The crude protein ($N \times 6.25$) content of grain may be of importance in determining its value as livestock feed or for use by the malting industry. Data from this study indicate that protein content of wheat and barley may be altered to some degree by fertilization but that it is also affected by variety, climate, and crop-management practices.

In general, applications of fertilizer nitrogen increase the protein content when more of this nutrient is taken up than is utilized in the growth needs of the cereal plants.

Data from samples taken from barley tests are used in table 12 to illustrate how fertilizer treatments affect the protein content of the harvested grain. The data shown are from individual locations but each figure is representative of a number of areas and conditions.

On soils with adequate phosphorus

In table 12, case 1 illustrates a situation in which nitrogen was acutely deficient. Yields were greatly increased by 15 pounds of nitrogen. Thirty and 45 pounds of nitrogen gave higher yields, but the rate of improvement became progressively less as higher amounts were applied. The per cent protein was not materially affected by the 15- to 30-pound rates of nitrogen. The 45-pound application, which had little effect on yield, clearly increased the protein content. The addition of phosphorus had no effect on yield or protein content.

Case 2 shows a condition in which nitrogen was only slightly deficient. Applications of fertilizer nitrogen had only a small effect on yield. Each added increment of nitrogen brought about an additional increase in protein. Here again, phosphorus had no significant effect on yield or per cent protein.

Case 3 illustrates how applications of nitrogen made late in the season after yields had already been determined can materially increase the protein content. Foliar sprays applied a week before bloom illustrate the magnitude of protein changes possible. Here protein was increased from 7.3 to 8.5 per cent by sprays of urea which supplied 44 to 66 pounds of nitrogen per acre.

Case 4 demonstrates that, where lack of moisture affects crop yields, nitrogen applications may cause a considerable increase in protein content of grain. Nitrogen applications made at planting time

Table 12.—Effects of Nitrogen Fertilizers on Yield and Protein Content of Barley on Soils with Adequate Phosphorus

Crop and cropping conditions	Nitrogen applied	Phosphorus applied	Yield	Protein content
	lb/A	lb/A	lb/A	per cent
Case 1. Rojo Barley, adequate moisture, acute nitrogen deficiency (Santa Clara County)	0	0	458	7.19
	0	40	570	7.38
	15	0	1,005	7.00
	15	40	940	7.00
	30	0	1,260	7.19
	30	40	1,358	7.43
	45	0	1,485	7.88
	45	40	1,388	8.25
Case 2. Tennessee Winter barley, adequate moisture, slight nitrogen deficiency (Yolo County)	0	0	1,644	10.5
	0	40	1,674	10.5
	15	0	1,828	11.06
	15	40	1,770	11.31
	30	0	1,824	12.31
	30	40	1,848	11.88
	45	0	1,818	13.13
	45	40	1,908	13.50
Case 3. Tennessee Winter barley on Yolo loam, late nitrogen applications from foliar urea sprays (Yolo County)	0	..	2,523	7.30
	22*	..	2,421	7.95
	44*	..	2,781	8.48
	66*	..	2,643	8.52
Case 4. Tennessee Winter barley, moderate nitrogen deficiency followed by late spring drought (Stanislaus County)	0	0	2,145	10.88
	0	40	2,318	10.69
	15	0	1,928	11.44
	15	40	1,725	11.63
	30	0	1,553	13.06
	30	40	1,560	12.69
	45	0	1,470	13.06
	45	40	1,530	12.63

* From 50, 100, and 150 lb urea/100 gal water applied 1 week before bloom.

stimulated additional tillering. Acute spring drought conditions prevailed; the soil moisture was not adequate to permit normal maturation of the increased number of heads. This resulted in reduced yields with shriveled grain higher in protein content and probably lower in starch than grain from unfertilized plants. The addition of phosphorus did not alter the effect of nitrogen on yield or per cent protein. Similar increases in protein content with little or no change in yield may be expected from nitrogen application when drought conditions are less severe.

Table 13.—Effects of Fertilizers and Cropping Conditions on Yield and Protein Content of Grains on Phosphorus-Deficient Soils

Cropping conditions	Nitrogen applied	Phosphorus applied	Yield	Protein content
	lb/A	lb/A	lb/A	per cent
Case 1. Atlas Barley on irrigated land, acute phosphorus deficiency, slight nitrogen deficiency (Merced County)	0	0	1,740	10.9
	0	20	2,618	10.0
	0	40	2,745	10.0
	0	80	2,895	9.2
	15	0	1,975	11.8
	15	20	3,315	10.0
	15	40	3,143	10.0
	15	80	3,030	10.1
	30	0	1,995	11.6
	30	20	3,293	10.5
	30	40	4,090	10.1
	30	80	3,420	10.2
	45	0	1,598	13.0
	45	20	3,773	10.4
	45	40	3,720	10.6
	45	80	3,848	10.1
Case 2. Mariout Barley, slight phosphorus deficiency, acute nitrogen deficiency, annual cropping (Napa County)	0	0	1,395	7.8
	0	20	1,485	7.7
	0	40	1,448	7.6
	0	80	1,448	7.7
	15	0	1,448	7.6
	15	20	1,635	7.2
	15	40	1,628	7.1
	15	80	1,898	7.6
	30	0	1,898	7.6
	30	20	1,980	7.6
	30	40	1,853	7.2
	30	80	2,385	7.4
	45	0	2,160	7.8
	45	20	2,423	7.6
	45	40	2,340	7.6
	45	80	2,813	7.8

On phosphorus-deficient soils

Both nitrogen and phosphorus may affect, to some degree, protein content of grain grown on soils deficient in phosphorus. The effects of nitrogen are similar to those observed on soils with adequate phosphorus, as described in the preceding section. There were, however, further effects of increased phosphorus supply.

In table 13, case 1 shows the effects of phosphorus fertilization on irrigated barley acutely deficient in phosphorus and moderately deficient in nitrogen. Nitrogen alone had little effect on yield, but

Table 13.—(Continued)

Cropping conditions	Nitrogen applied	Phosphorus applied	Yield	Protein content
	lb/A	lb/A	lb/A	per cent
Case 3. Onas Wheat, acute phosphorus deficiency, slight nitrogen deficiency, fallow cropping, adequate moisture (Monterey County)	0	0	855	10.6
	0	20	1,298	10.3
	0	40	1,260	10.3
	0	80	1,470	10.5
	15	0	953	11.8
	15	20	1,350	10.8
	15	40	1,343	10.9
	15	80	1,388	10.4
	30	0	953	12.1
	30	20	1,463	11.4
	30	40	1,628	10.9
	30	80	1,785	10.9
	45	0	998	12.3
	45	20	1,538	12.6
	45	40	1,710	12.7
	45	80	1,613	12.1
Case 4. Arivat Barley, acute phosphorus deficiency, nitrogen adequate, fallow cropping, spring drought (Monterey County)	0	0	908	14.9
	0	20	1,305	14.4
	0	40	1,343	15.9
	0	80	1,200	15.4
	15	0	1,073	15.4
	15	20	1,260	15.2
	15	40	1,178	16.1
	15	80	1,275	16.4
	30	0	900	14.9
	30	20	1,155	15.2
	30	40	1,163	16.4
	30	80	983	17.1
	45	0	863	16.1
	45	20	1,028	15.7
	45	40	1,140	15.6
	45	80	1,148	14.5

protein content was increased by nitrogen applications. The use of phosphorus alone and at each nitrogen level greatly increased yields, which in turn brought about a definite decrease in protein values. None of the combination treatments provided enough nitrogen to increase the protein content of the grain.

Case 2 illustrates conditions on soil acutely deficient in nitrogen and moderately responsive to phosphorus. Here nitrogen alone increased yield of barley from 1,395 to 2,160 pounds per acre, with benefit from each increment of nitrogen. Nitrogen alone had no effect on protein. Phosphorus alone tended to increase yield and to depress per cent protein very slightly. Additions of phosphorus at each nitrogen level increased yields clearly and tended to reduce protein content to a slight extent.

Case 3 represents a situation with adequate moisture where phosphorus was acutely deficient and nitrogen only slightly deficient after a period of fallow. Yields were not significantly increased by nitrogen alone, since phosphorus limited growth, but protein values were increased slightly by each increment of nitrogen. After phosphorus was applied, nitrogen treatments increased yields up to a maximum at 30 pounds nitrogen with no change in per cent protein. The 45 pounds of nitrogen treatment, which caused no further increase in yield, did show higher protein values.

Case 4 indicates the effects of phosphorus on protein values of barley where severe spring drought prevailed. Here the soil was acutely deficient in phosphorus, but had a fair nitrogen supply after fallow. Applications of nitrogen alone had little effect on yield, but tended to increase protein content. Phosphorus alone, however, increased yields but, because of limited moisture, tended to produce "light grain" of higher protein content. The addition of nitrogen to phosphorus caused more vegetative growth, tended to reduce yields and to produce grain of higher protein content. This case represents an extreme drought condition. The use of phosphorus on fallow, phosphorus-deficient lands with limited spring rainfall but with moisture at depth in the soil usually stimulates early growth and deeper rooting, so that well-filled grain is usually produced with little or no change in protein composition.

Effect of Fertilization on Malting Quality of Barley

Barley must meet exacting quality requirements if it is to be used for malting. Six-row varieties, such as Atlas 46 and Tennessee Winter, and the two-row variety Hannchen are suitable if they are of proper protein content and have well-filled, plump kernels.

The malting process involves steeping, germination, and kilning of the whole grain. Barley grain is composed of two principal parts, the germ, or embryo, which contains most of the protein, and the endosperm, which is composed principally of starch. During the "sprouting" or restricted germination phase of malting, enzymes are formed or released from inactive forms in the grain. In subsequent uses of malt, the enzymes liquefy the starch of the grain and convert it into soluble, fermentable sugars, which may then either be fermented by yeast to form alcohol or used as such in malt syrups and other food products.

The evaluation of barleys for use of the malting or brewing industries involves a number of measurements, and preferably includes experimental malting and malt analysis. This brief discussion will be limited primarily to the relationship between the protein content of barley and the malt quality factors—per cent malt extract and diastatic power. Malt extract is the percentage of the malt that is made soluble during "mashing" in water, and is related to the amount of beer which may be expected from a sample of barley after malting. Diastatic power, expressed in degrees Lintner (°L), is a

measure of the starch-converting power of malt produced from a barley.

Relation of per cent protein of barley to per cent malt extract and diastatic power

Varieties of barley differ rather widely in extract percentage and diastatic power of malts prepared from them. Within a variety, these two malt factors are closely related to protein content. The relationship between per cent protein of Atlas barley and the yield of malt extract, and the diastatic power of its malt are shown in figure 7. It will be noted that malt extract decreased as the protein content became greater. Diastatic power, however, became greater with increasing barley protein values.

Effects of fertilizer and soil management on malting characteristics of barley

Commercial fertilizers may be expected to influence malting quality when the applied materials cause change in the protein content of the grain. The factors affecting protein content have been discussed in the preceding section. Malting data on Atlas barley samples from the 1950 Merced County test illustrate (table 14) how fertilizer treatments which alter yield and protein content of grain also affect diastatic power and per cent malt extract.

At this location, phosphorus was acutely deficient. Because of this deficiency, nitrogen alone had no effect on

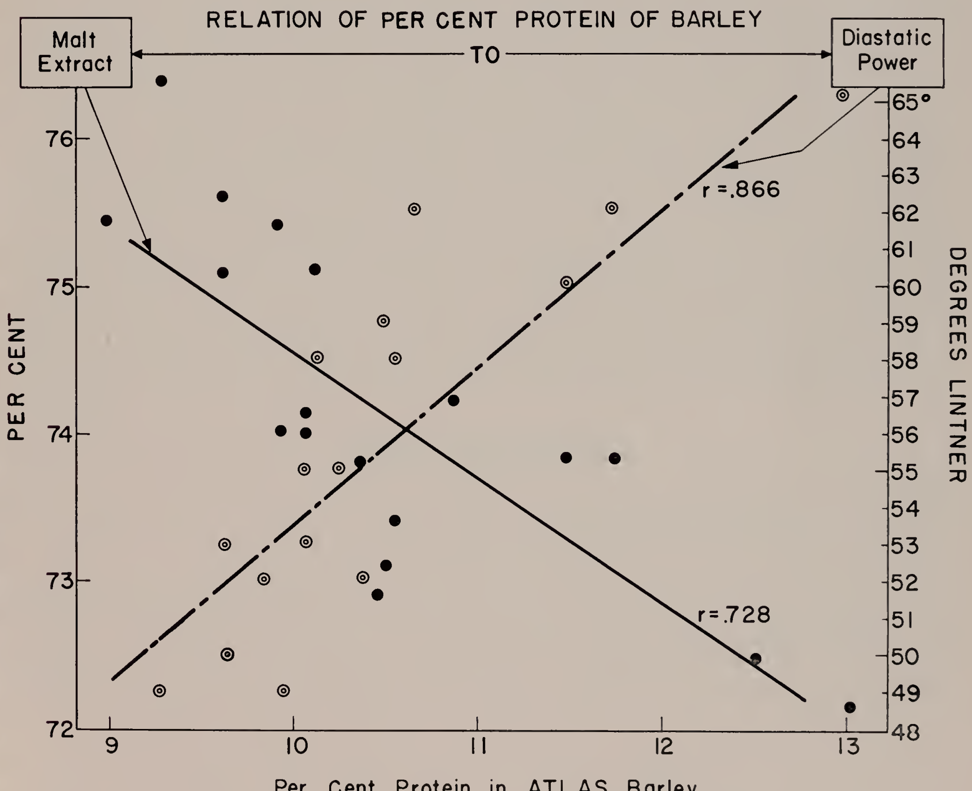


Fig. 7. Malt extract (black dots) decreased with increased protein content of barley, but diastatic power (circles) became greater with higher protein values.

Table 14.—Effect of Fertilizer on Yield and Malting Quality of Atlas Barley (Merced County, 1950)

Fertilizer treatment	Yield	Protein content	Diastatic power	Malt extract
	lb/A	per cent	°L	per cent
None . . .	1,740	10.8	62	74.2
N_{45}.	1,598	13.0	65	72.1
P_{80}.	2,896	9.3	49	76.4
$N_{45}P_{80}$. . .	3,820	10.1	55	74.0

yield but did increase the protein content of the grain. Diastatic power was increased and yield of malt extract was reduced in proportion to change in protein.

Application of phosphorus alone increased yields. Here the protein content was reduced since the nitrogen supply from the soil had to be distributed among the larger number of barley grains constituting the 66 per cent yield increase. Diastatic power was materially reduced as was per cent protein, while per cent malt extract was increased.

Where both nitrogen and phosphorus were applied, the malt extract and protein values remained unchanged. In this case the added nitrogen that increased yield was only sufficient to maintain the protein content of the larger barley crop resulting from nitrogen and phosphorus treatment.

It is to be expected that malting quality as measured by per cent *malt extract* will be *reduced* when nitrogen applications are materially greater than needed to take care of increased yield caused by fertilization. Rates of nitrogen that increase yield but do not alter protein content appreciably will have little or no effect on malting quality. Usually the desirable rates of nitrogen application for production of malting barley will be those which give slightly less than maximum yield. Higher nitrogen applications may be expected to increase protein content and reduce malting quality.

It is important to recognize that *nitrogen supply in relation to growth* is more important than the actual amount of fertilizer currently applied. When barley follows a heavily fertilized vegetable or field crop or a legume crop whose residue increases the soil nitrogen supply, we may expect barley of higher than usual protein and reduced malting quality. Similarly, midseason irrigations, which increase nitrification of organic nitrogen in a peat or muck soil, may increase the supply of nitrates and have the same effect in increasing protein as would a late application of commercial fertilizer.

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Table 1A.—Summary of Results of 221 Grain Fertilizer Tests in California

County	Number of plots	No. of observed responses to fertilization				Kind of grain and no. of responses			Farm Advisors who contributed results
		Nitrogen only	Nitrogen plus phosphorus	Phosphorus only	None	Barley	Wheat	Oats	
Alameda	1	..	..	1	..	..	..	..	V. D. Miller
Butte	11	8	3	..	..	8	3	..	E. F. Azevedo, M. D. Morse
Colusa	14	8	2	1	3	13	1	..	A. R. Melis
Contra Costa	5	..	1	..	4	5	..	..	A. M. Goff
Fresno	6	1	..	2	3	3	3	..	J. O. Hoyt
Glenn	3	1	1	..	1	3	..	..	M. D. Miller
Imperial	7	4	..	..	3	5	2	..	R. S. Ayres, W. Parnicky
Kern	2	1	1	..	..	1	1	..	J. D. Axtell, R. S. Sherman
Kings	4	3	..	..	1	4	..	..	O. D. McCutcheon
Lassen	2	2	..	..	..	..	2	..	P. W. Lamborn
Los Angeles	3	..	..	..	3	3	..	..	L. B. Peterson
Madera	7	1	3	2	1	3	4	..	E. L. Garthwaite, W. E. Emrick
Merced	6	1	2	1	2	4	2	..	C. C. Conley
Modoc	2	1	..	..	1	2	..	..	K. C. Baghott
Monterey	13	3	2	2	6	9	4	..	H. D. Hollembeak
Napa	3	2	1	..	..	2	1	..	D. I. Grover
Orange	3	..	2	..	1	3	..	..	W. N. Cory
Placer	3	..	2	1	..	..	3	..	R. D. Davis
Riverside	13	3	2	2	6	7	4	2	O. D. Harvey, W. B. Gardner
Sacramento	3	..	..	2	1	2	1	..	T. Lyons, J. T. Peterson
San Benito	4	1	..	..	3	3	1	..	P. D. Pattengale, D. M. Irving
San Diego	14	2	8	4	..	12	..	2	B. J. Hall
San Joaquin	10	1	7	1	1	3	3	4	R. S. Baskett
S. L. Obispo	11	3	1	5	2	4	7	..	P. S. Berryman
San Mateo	5	2	2	1	..	3	..	2	J. J. McNamara
S. Barbara	2	1	..	..	1	2	..	..	E. F. Smyth
Santa Clara	2	2	..	..	..	2	..	..	G. D. Shambrook
Santa Cruz	1	..	..	..	1	1	..	..	J. W. Melendy
Shasta	8	5	1	..	2	2	6	..	L. J. Berry
Siskiyou	10	6	2	..	2	3	7	..	M. V. Maxwell
Solano	5	1	1	2	1	2	3	..	V. W. DeTar
Stanislaus	9	..	5	1	3	9	..	..	V. P. Osterli, E. E. Stevenson
Sutter	3	..	2	1	..	..	3	..	R. C. Pearl
Tehama	6	4	2	..	..	6	..	..	D. M. Smith
Tulare	7	1	3	2	1	5	2	..	R. L. Worrell
Ventura	3	..	..	1	2	3	..	..	R. A. Brendler
Yolo	6	1	3	..	2	6	..	..	T. S. Torngren
Yuba	4	1	1	2	..	3	1	..	W. M. Anderson
Total, 38 counties	221	70	60	34	57	149	62	10	

Table 2A.—Relation of Soil Profile Group and Soil Series to Response of Grain to Nitrogen and Phosphorus Fertilizers

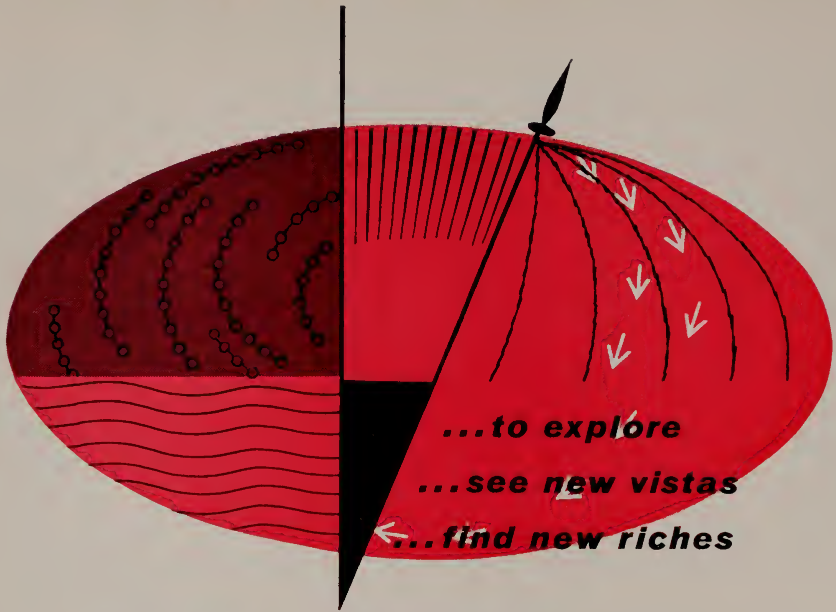
Soil series	No. of observed responses to fertilizers				
	None	N only	P only	N P	Total
Group I — Recent alluvial soils					
1. Cajon	..	1	..	1	2
2. Columbia	..	2	1	..	3
3. Corralitos	1	..	..	..	1
4. Cortina	1	..	..	..	1
5. Dublin	1	..	..	..	1
6. Elder	..	1	..	..	1
7. Egbert	1	..	2	..	3
8. Foster	1	1	..	..	2
9. Hanford	1	..	1	..	2
10. Hesperia	..	1	..	..	1
11. Holtville	2	1	..	2	5
12. Panoche	2	1	..	..	3
13. Ryde	..	1	..	..	1
14. Surprise	..	1	..	..	1
15. Sycamore	..	1	..	..	1
16. "Tulelake Muck"	1	1	..	..	2
17. Vina	1	3	..	..	4
18. Yolo	2	2	..	..	4
Total	14	17	4	3	38
Group II — Young alluvial soils					
1. Arbuckle	..	1	..	2	3
2. Chino	1	..	1	1	3
3. Esparto	..	1	..	..	1
4. Exeter	1	..	..	..	1
5. Greenfield	3	2	..	..	5
6. Imperial	1	2	..	..	3
7. Sacramento	..	1	..	..	1
8. Temple	..	1	..	..	1
9. Tulare	..	3	..	..	3
Total	6	11	1	3	21
Group III — Old alluvial soils					
1. Adelanto	..	..	..	1	1
2. Chualar	..	..	1	..	1
3. Ducor	..	..	2	..	2
4. Gridley	..	2	..	..	2
5. Harrington	..	3	..	..	3
6. Lockwood	..	1	1	1	3
7. Montezuma	..	1	1	..	2
8. Myers	1	2	..	..	3
9. Ojai	..	..	1	..	1
10. Orestimba	1	..	..	..	1
11. Pleasanton	1	1	..	..	2
12. Ramona	3	2	2	..	7
13. Rincon	3	1	..	..	4
14. Tehama	1	2	..	1	4
Total	10	15	8	3	36

Table 2A.—(Continued)

Soil series	No. of observed responses to fertilizers				
	None	N only	P only	N P	Total
Group IV — Claypan soils					
1. Cachuma	1	..	..	..	1
2. Cometa	..	..	..	1	1
3. Coombs	..	..	..	1	1
4. Corning	..	..	1	3	4
5. Hartley	..	..	..	1	1
6. Hillgate	2	1	..	1	4
7. Huerhuero	1	..	4	..	5
8. Kimball	..	..	..	1	1
9. Merriam	..	..	..	1	1
10. Olivenhain	..	..	..	1	1
11. Placentia	1	..	..	1	2
12. Standish	..	1	..	..	1
13. Watsonville	..	..	1	1	2
Total	5	2	6	12	25
Group V — Hardpan soils					
1. Fresno	1	..	..	1	2
2. Hames	..	..	2	..	2
3. Lewis	..	..	..	1	1
4. Madera	..	..	1	..	1
5. Monserate	..	..	..	2	2
6. Montague	..	1	..	..	1
7. Redding	1	..	..	4	5
8. Rocklin	..	..	1	4	5
9. San Joaquin	1	..	6	3	10
10. Stockton	..	1	..	..	1
Total	3	2	10	15	30
Groups VII, VIII, IX — Upland soils developed in place					
1. Altamont*	..	1	2	3	6
2. Diablo	..	..	1	1	2
3. Holland	..	1	..	1	2
4. Linne	..	..	2	3	5
5. Los Osos	..	1	1	..	2
6. Olympic	..	1	..	..	1
7. Sierra	..	..	..	2	2
8. Sites	1	..	..	..	1
9. Vista	..	..	1	..	1
10. Whitney	..	..	1	..	1
Total	1	4	8	10	23

* Includes some soils formed on soft stratified materials and mapped as Altamont in older soil surveys, tentatively reclassified as Cometa-Whitney Complex.

PURPOSES OF A UNIVERSITY...



"I like to compare scientific research to mountain climbing in an unexplored range. Considerable preparation, training, and a strong motivation are required to get up to the upper altitudes even if no one particular stretch of the way is particularly difficult. But once there, it is relatively easy for one to see vistas or even to stumble across new riches that people of equivalent ability who have stayed behind, have no possibility to see or to find."

GLENN T. SEABORG
Nobel Laureate in Chemistry, 1951

(From his address at the Secondary Education Board Conference, San Francisco, April 5, 1957)